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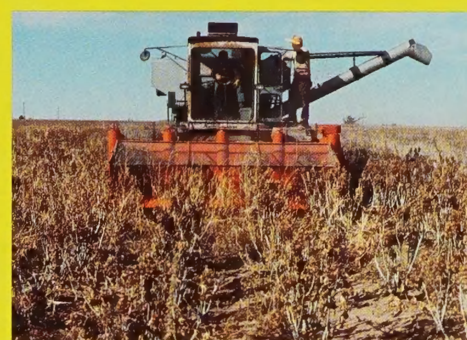
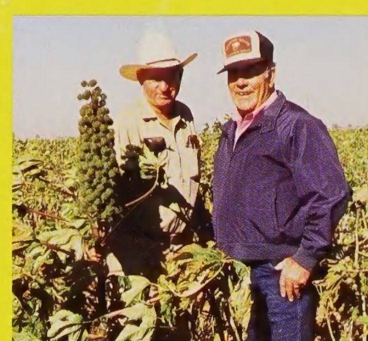
May 1991

Castor:

Assessing the Feasibility of U.S. Production





Castor:

Assessing the Feasibility of U.S. Production

U.S. Department of Agriculture
Cooperative State Research Service
Office of Agricultural Materials

and

Texas A&M University

Summary of Workshop
held at Plainview, Texas
September 18-19, 1990

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Abstract

The U. S. Department of Agriculture and Texas A&M University sponsored a workshop September 18-19, 1990, in Plainview, Texas, to assess the feasibility of domestic castor production. After reviewing the status of castor production, processing, and uses, representatives from the castor oil industry, the farm community, academia, and government outlined recommendations for the development of castor as a domestic crop. This report summarizes the information and recommendations discussed at the workshop.

Acknowledgements

The authors wish to thank all of the workshop participants for their input, particularly Jeane and Lee Browning, Ken Carlson, Elbert Harp, Robert Hawkins, Frank Naughton, Bob Pillow, K.C. Rhee, and Robert Vignolo. Jeane Browning, Ken Carlson, Robert Hawkins, and Robert Vignolo reviewed the report and provided valuable comments. Some photographs are provided courtesy of Browning Seed, Inc.

Cover photographs: (top left) examples of the types of products that use castor oil—grease, beverage can coatings, soaps, and lipstick; (bottom left) mature seed spike (raceme) of castor, an individual capsule and seeds, and a jar of oil; (top right) harvesting castor in Texas; and (bottom right) farmers with a seed spike in a field of castor.

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Castor oil is one of the oldest industrial products from agriculture, having been used by ancient Egyptians in their lamps. In modern times, manufacturers have developed many products using castor oil and its derivatives, including lubricants, nylon, coatings for food and beverage containers, and cosmetics. Castor oil derivatives (ricinoleic and sebacic acid) are important ingredients in lubricants for jet aircraft and military equipment; they are part of the Department of Defense's strategic and critical materials program.

Currently, the United States imports all of its castor oil. The dependence on fluctuating world supplies, in combination with unstable prices, has hindered corporate planning and investment. Therefore, castor oil users are interested in working with processors and farmers to re-establish domestic production.

To address this issue, the United States Department of Agriculture (USDA) Cooperative State Research Service's (CSRS) Office of Agricultural Materials and Texas A&M University sponsored a workshop September 18-19, 1990, in Plainview, Texas, to assess the feasibility of domestic castor production. Representatives from the castor oil industry, the farm community, academia, and government were invited to attend based on their expertise in castor production, processing, and uses.

The 29 participants reviewed the entire system of crop production, processing, manufacturing, marketing, and uses, as well as the history of castor in the United States and international production and trade. They discussed opportunities and hindrances, considering technical, economic, and institutional factors. One of the highlights was discussion of current private sector efforts to revive domestic production in the High Plains of Texas.

A number of factors have changed since domestic castor production was abandoned in the early 1970s. Since the United States became dependent on the world market for castor oil, U.S. wholesale prices have risen and become more unstable. Even within a year, castor oil prices have sometimes varied as much as 25 percent.

World production continues to vary. In other countries, castor generally is grown under dryland conditions. It is often intercropped—planted with other crops in a field—or harvested from wild stands. Seed is gathered by hand. Yields in the larger producing nations, such as Brazil and India, are usually less than 600 pounds per acre.

Castor oil buyers are concerned about supply availability and price fluctuations. Unstable prices have resulted in firms shifting to petroleum feedstocks, which are now becoming more costly. Because of market instability, firms have not invested in research and development to expand use.

During the 1960s and early 1970s, castor production centered on the High Plains of Texas. Current efforts to revitalize domestic production focus on this area. Browning Seed, Inc., has begun a seed multiplication program and may offer contracts to farmers for commercial production in 1991. Irrigated yields are expected to be over a ton of seed per acre.

With support from Union Camp Corporation and CasChem, Inc., the major U.S. buyers of castor oil, Browning Seed has developed, tested, and is patenting an improved castor harvester. This machine will lower harvesting costs and remove a major barrier to domestic production.

Farm prices for other crops produced in the High Plains were quite favorable in the early 1970s, thus fostering the decline in castor production. However, prices for traditional crops have declined. According to an economic evaluation of 1990 production costs and returns for the High Plains, castor would be an attractive crop for farmers. In addition, the 1990 Food, Agriculture, Conservation, and Trade Act may provide opportunities for castor production by giving farmers more planting options.

Negotiations are underway with a major oilseed processor to crush castor seed at a plant in Plainview, Texas. The plant will need to be modernized to incorporate new technology. A process to detoxify and deallergenate castor meal is now available. Extruders, the most recent advance in oil extraction machinery, are also worth considering.

Yet, significant opportunities exist to complement ongoing private sector activities. Continued teamwork among industry, academia, and government—like that demonstrated at the workshop—will boost these efforts. In concluding the workshop, participants developed recommendations to reestablish and sustain castor as a viable domestic crop. They are listed beginning with those related to production and ending with uses.

- A crop improvement program involving the private and public sectors is needed to develop improved varieties with higher yields, greater oil content, increased resistance to capsule mold, and other desirable properties.

- Approval of pesticides for use on castor would help farmers in their control of weeds and insects. Further research on capsule mold would also be useful.

- Flexibility in USDA commodity programs would be beneficial for farmers wanting to grow nontraditional crops like castor. In the past, many felt constrained by base-acreage requirements for program crops. Some workshop participants expressed the desire for assurances that program "rules" would not change, as has occurred in the past.

- A program to educate growers and provide technical support is needed.

- Three-to-5-year contracts for farmers can provide production stability. Thereby, industry and farmers would share the risks of fluctuating world prices and supplies.

- Bridge financing is needed so farmers can be paid at harvest while the oil is sold throughout the year.

- Industry may want to validate the use of extruders in processing castor seed. Development of in-plant systems to monitor allergen levels would also be advantageous.

- Feeding trials are needed to determine the value of castor meal in livestock rations. The information gained will be used in applying for Food and Drug Administration (FDA) approval of castor meal as a feed ingredient sold in interstate commerce, although large market potential exists in Texas.

- Workshop participants from the private sector expressed the desire for a "roadmap" that would help businesses in complying with Government regulations when commercializing new industrial products. The guidelines could be developed jointly by FDA, USDA, the Environmental Protection Agency, and the Occupational Safety and Health Administration. Entrepreneurs could use such a document as a resource in gathering information on Federal Government regulations.

- Stable castor oil prices would help curtail loss of markets. Furthermore, price stability would foster investment in new research and market expansion.

- Development of new castor oil derivatives and applications is needed. This work could be undertaken by private industry in cooperation with Agricultural Research Service (ARS) regional laboratories and universities.

• • Introduction • •

Facts About Castor

- The United States imports 100 percent of its castor oil.

- Markets for castor oil exist domestically and internationally but some have been lost due to the instability of world supply and prices.

- Castor oil possesses unique characteristics for industrial applications. Some of these properties led the Department of Defense (DOD) to classify the castor derivatives ricinoleic and sebacic acid as strategic and critical materials.

- The High Plains of Texas has the climate, soil, irrigation water, and grower desire and experience to produce castor.

Workshop participants examine a prototype castor harvestor.

Castor Workshop

Industry representatives, the farm community, and the public sector recently have demonstrated an interest in again producing castor in the United States. As a result, the Office of Agricultural Materials, USDA Cooperative State Research Service (CSRS) [1], with the assistance of Texas A&M University, convened a workshop in Plainview, Texas, September 18-19, 1990.

The purpose of the workshop was to:

- Evaluate the potential for domestic production and processing of castor as a source of hydroxy fatty acids for industrial products.

- Identify barriers and, if warranted, develop recommendation for action.

Twenty-nine individuals attended—18 from the private sector and 11 from the public sector. Users, crushers, equipment manufacturers, farmers, and a banker and a consultant were among the private sector participants. USDA representatives include individuals from CSRS, the Agricultural Research Service (ARS), and the Economic Research Service (ERS). An agronomist, processing specialist, chemical engineer, and agricultural economist represented Texas A&M University. Two former commercial growers from out of State, including one agronomist from the University of Missouri, also attended. (See Appendix A for list of participants.)

Participants discussed domestic production, processing, and utilization of castor. A field tour gave people the opportunity to see a castor crop and view a prototype mechanical harvester.

Workshop participants agreed that domestic production of castor can be successful. However, some hurdles remain. Teamwork will be necessary among all sectors to achieve a viable long-term industry.

The purpose of this report is to summarize the discussions held at the workshop. Additional information is provided to give the reader a better understanding of castor and its uses. A short history of castor in the United States prefaces a discussion of international production and trade. This is followed by sections on castor production and processing, oil characteristics and uses, and workshop recommendations.

History

Early settlers grew castor for medicinal purposes and for use as a lubricant. Commercial production existed in the central United States as early as 1850. During that period, over 23 crushing mills reportedly were operating [2]. However, the crushing industry suffered from fluctuating local production. As a result, new mills were built on the east and west coasts to crush imported castor seed.

In the mid-1930s, Baker Castor Oil Company began an effort to develop a domestic crop for its California processing plant. Later on, W.E. Domingo headed the agronomic and plant improvement program for Baker [3]. Soon, farmers were growing castor in the Imperial and San Joaquin Valleys [4].

During World Wars I and II, domestic production was encouraged because of castor oil's strategic value [5]. Derivatives of castor oil are key ingredients in hydraulic fluids, greases, and lubricants for military equipment.

The Korean conflict renewed efforts to produce castor domestically, mainly in Texas, Oklahoma, California, and Arizona [6]. Industry and government cooperated in numerous ways, such as developing improved varieties and basic mechanical harvesters, and offering contracts for production. Acreage reached 84,000 in 1951 [3, 7].

In the 1950s, higher valued crops—such as vegetables, fruits, and nuts—began displacing castor in the Imperial and San Joaquin Valleys [8]. The High Plains of Texas became an important growing area because of its productive land, available irrigation water, an adequate growing season, low relative humidity to deter disease, and a killing frost to facilitate harvest [5]. In California, growers used defoliants to remove leaves prior to harvest; the killing frost eliminated the need for this in Texas.

By 1959, Texas became the leading producer of castor [5]. In the late 1960s, over 75,000 acres of castor were grown in the State.

The plant improvement efforts initiated by USDA and the Texas Agricultural Experiment Station during the early 1950s eventually led to the development of the dwarf-internode "Hale" and "Lynn" cultivars. By the early 1960s, breeders had developed hybrids that were higher yielding and more amenable to mechanical harvest [5]. These hybrids were only half as tall (4 to 6 feet) as earlier commercial castor varieties.

Additional agronomic and harvesting research was done at Stillwater, Oklahoma; Davis, California; and College Station and Lubbock, Texas. Significant progress resulted but the crop has possibilities for further development.

Dr. Ray Brigham in field of Hale castor, a variety he developed in the 1960s.

USDA and universities have not conducted appreciable research and development on castor in the past 15 years. In the early 1970s, when prices for traditional crops were high, USDA discontinued most efforts to find new industrial uses for agricultural commodities including castor. Only now is a concerted effort underway to rejuvenate research and development on industrial products [9, 10].

U.S. production of castor ceased in the early 1970s. Since then, only a few acres have been planted. Most seed lines were lost as a result. At one time, only 40 to 50 pounds of "Hale" seed existed in the United States.

Castor's Demise in Texas

Four major factors combined to cause the demise of domestic castor production and processing.

A primary reason revolved around contract negotiations. In 1972, castor oil buyers and the High Plains farm cooperative involved in crushing castor met to renew their annual contract. Because the cooperative crushed the seed on behalf of farmer members, the price paid for seed was the focus of the negotiations. Both parties walked away from the bargaining table due to disagreements over the seed price, even though the difference was less than 1 cent per pound. Each side felt confident that the other would concede. Neither did. Hence, no contract resulted.

Low world prices for castor oil led buyers to take a firm stand in the negotiations, since they could obtain cheaper supplies elsewhere. Low prices enticed buyers to take immediate gains and risk losing U.S. production, which had helped stabilize domestic prices during the 1950s and 1960s. Today, industry representatives acknowledge that this short-term outlook was not wise. Since U.S. production ceased, domestic buyers have become more vulnerable to fluctuations in world prices.

A third factor was the higher prices being paid for other crops grown in the High Plains. Growers felt they needed higher prices for castor for it to compete with the returns they were receiving from other crops. This contributed to the cooperative's firm stance in the contract negotiations. When talks failed, farmers turned to growing sunflowers, a new crop at the time.

A final reason involved changes in Federal commodity programs. From 1968 to 1971, the Government provided price support to farmers who grew castor. As part of the program, the Government offered to buy up to 30 to 35 million pounds of oil if companies could not sell it on the open market, given the sup-

Figure 1.
Wholesale Castor Oil Prices, 1965-90.

[1]Annual average prices for No. 1 castor oil, tank car lots.
Source: [11].

port price they were required to pay to farmers. In some years, the Government also allowed farmers to grow castor on set-aside acreage not planted to major program crops. The Government discontinued the support program in 1972, and each year farmers were unsure if set-aside planting would be permitted. This uncertainty over Government regulations weakened the foundations for negotiations. (See Appendix B for information on the Federal programs.)

U.S. production ceased because contract negotiations failed. Price fluctuations rapidly became a reality for domestic oil users. Annual average wholesale prices for castor oil rose from 23.3 cents per pound in 1972 to highs of 52.6 cents in 1974 and 72.7 cents in 1984 (figure 1). Even after accounting for inflation, annual prices often changed by 10 cents per pound. Monthly prices were just as unstable; they frequently varied by more than 25 percent within a year [11]. (See Appendix C for annual and monthly castor oil prices.)

These wide fluctuations cause castor oil markets to be supply driven rather than demand driven. Price instability imposes severe handicaps on importers and users; it impacts cash flow, makes corporate planning difficult, and discourages investment in new products.

Industry champions, Frank Naughton and Robert Hawkins (center), are working with Browning Seed, Inc., to develop domestic castor production.

Some users of castor oil sought alternative materials, primarily petroleum-based feedstocks. Others maintained their uses of castor oil, but did not invest in research and market development. Hence, the domestic market for castor oil has not grown. However, the potential still exists for expansion if prices can be stabilized.

What Has Changed

Some significant changes have occurred since castor disappeared from Texas. The private sector now believes that a domestic industry can be reestablished and thrive with proper nurturing. They are investing in its future.

Recent increases in petroleum prices and instability in the Middle East make castor oil more competitive with petroleum feedstocks. Castor oil could be substituted as a raw ingredient in many products. For example, it is used in producing nylon-11, whereas petroleum feedstocks are the basis for most other nylon formulations.

Environmental concerns also improve the opportunity to use agricultural materials, such as castor oil, for industrial uses. Not only is it biodegradable, it is a renewable raw material. On the other hand, petroleum is a diminishing stock resource. Consumers' desire for natural products further brighten castor's prospects. However, the allergen and toxins of castor require proper management and control, or environmental concerns about health and safety could arise.

U.S. castor industry leaders, such as Union Camp Corporation and CasChem, Inc. (both based in New Jersey), are seeking a reliable source of domestic castor oil at a stable price [12]. These firms have expressed interest in contracting for oil. They foresee domestic production as supplementing imports, at least in the short term.

Within the past year, Browning Seed, Inc. of Plainview, Texas, with the encouragement and support of the U.S. castor oil industry, has initiated efforts to develop a source of improved seed for planting. This includes the long-term process of generating new castor hybrids. Browning Seed also has developed a more efficient mechanical harvester.

Castor has excellent private sector champions and a strong supporting cast. Robert Hawkins served many years as a castor oil purchasing agent for Union Camp and understands the buyers' position. Frank Naughton represents CasChem, the largest U.S. user of castor oil. Jeane Browning of Browning Seed has provided leadership in the agricultural sector.

Castor grows in tropical and temperate regions throughout the world, either wild or cultivated [13, 14]. Although it can be raised in many locations, a few countries dominate world production and trade. The small number of major producing and exporting nations presents a scenario where market control of supply and prices may be possible.

Castor Seed

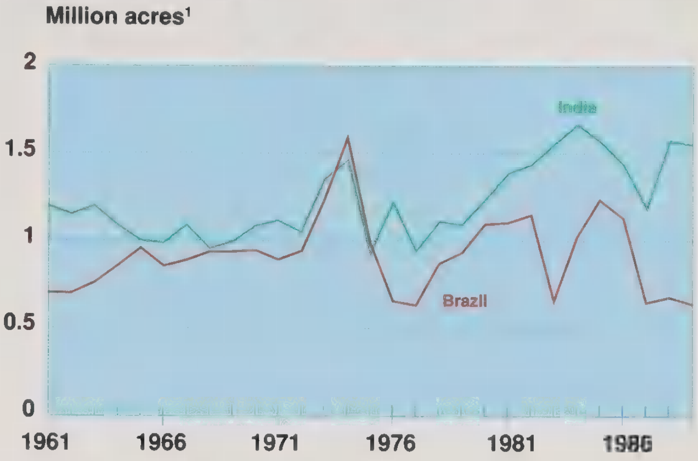
According to data published by the United Nations Food and Agriculture Organization (FAO), more than 30 countries reported growing castor in the 1980s. India, China, and Brazil are the major producers [15]. They accounted for over three-quarters of the world's castor seed harvested during 1986-89. The Soviet Union, Paraguay, Thailand, and Ethiopia produced most of the remainder (Appendix D, table 6).

Since 1961, India and China have expanded their output of castor, while Brazil has experienced fluctuating production. Output declined in several minor-producing countries, notably Sudan, Tanzania, South Africa, Pakistan, and Ecuador. Along with the United States, Argentina and Libya stopped growing castor in the 1970s.

Worldwide, practically all castor is grown under dryland conditions and hand harvested. Much of the castor seed is gathered from native stands or produced in an intercrop system where two or more crops are planted in the same field. These conditions contribute to wide fluctuations in acreage and yield. For example, between 1961 and 1989, harvested area in Brazil ranged from a high of 1.58 million acres to a low of 0.63 million. Indian acreage was only a little less variable (figure 2). During the 1960s and 1970s, yields were relatively stable, but that situation changed for both Brazil and India in the 1980s (figure 3). Countries currently producing castor report average yields of under 1,000 pounds per acre and most indicate yields are below 600 pounds [16].

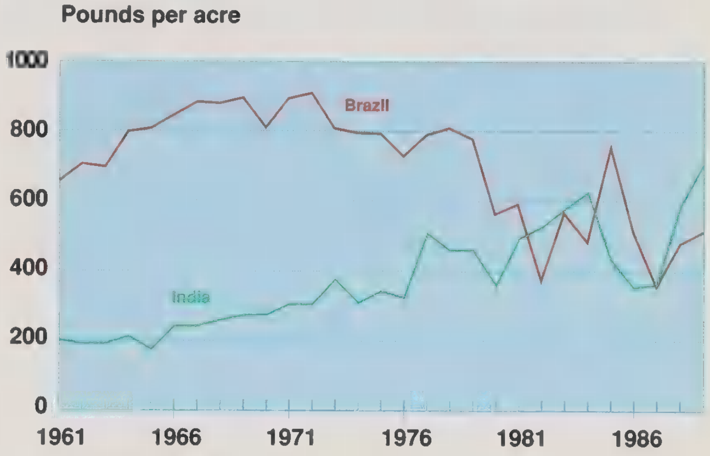
The United States is not the only industrialized country interested in domestic production as a hedge against fluctuating world supplies and prices. France has initiated a program to produce castor as a part of an effort within the European Community to encourage the use of agricultural crops as industrial raw materials [17]. The French program is evaluating castor's potential and possible hindrances. Apparently, mechanized harvest-hulling equipment has not yet been developed. Capsule mold also may be a problem because of higher humidities than those encountered on the Texas High Plains.

Figure 2.
Castor Acreage in Brazil and India.



¹Harvested area.
Source: Data from [15].

Figure 3.
Castor Yields in Brazil and India.



Source: Data from [15].

Most major castor-producing nations prohibit or discourage export of seed to promote internal processing of the oil [18]. India banned seed exports in 1952 and Brazil did likewise in 1959 [13]. Therefore, China is the only major producer that sells seed. During 1986-88, China accounted for over four-fifths of world exports of castor seed. Paraguay and the Philippines were distant seconds (Appendix D, table 7) [19].

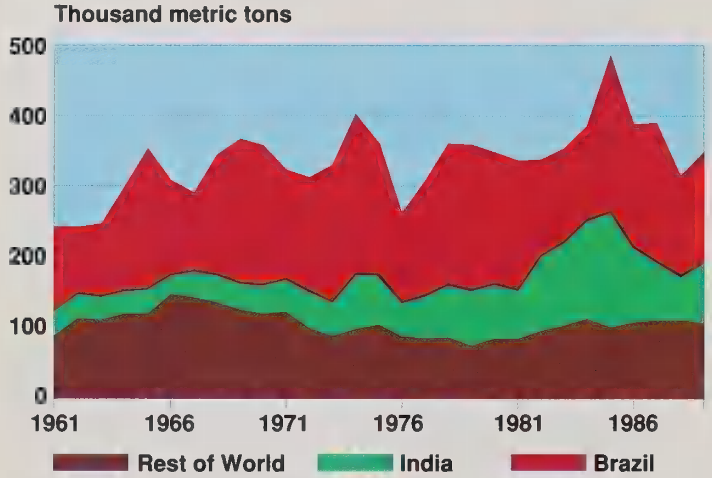
Brazil has imported seed for 20 years to supplement its domestic crush of castor. Thailand recently began doing so. The other large importers of seed—Germany, Japan, and Italy—are not domestic producers and therefore buy all their supplies from world markets. Together, these five countries account for almost all castor seed imports.

Castor Oil

Processing of castor seed into oil occurs primarily in Brazil, India, China, the Soviet Union, Germany, Japan, and Thailand (Appendix D, table 8). Historically, Brazil and India have been the major producers and exporters of oil. It is also important to note that they have been responsible for much of the fluctuations in world supply since 1961 (figures 4 and 5).

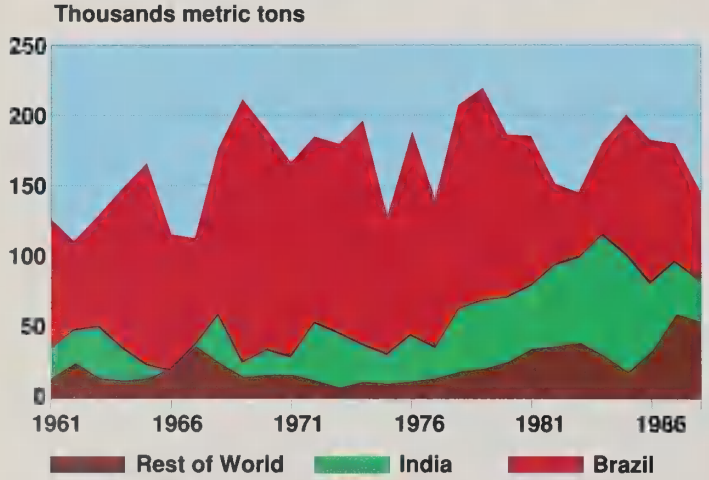
During 1986-88, France, the United States, the Soviet Union, West Germany, and the United Kingdom were the top five importers—buying roughly three-quarters of the oil traded. Imports by France and the Soviet Union have increased since 1961-65, while those from the United States and United Kingdom have dropped (Appendix D, table 9).

Figure 4.
World Production of Castor Oil, 1961-89.



Source: Data from [15].

Figure 5.
World Exports of Castor Oil, 1961-88.

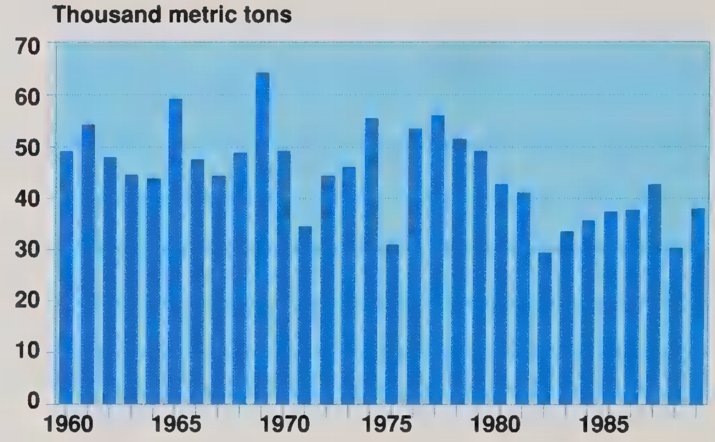


Source: Data from [19].

In 1989, the United States imported 37,875 metric tons of castor oil (figure 6), mostly from Brazil [20]. Union Camp and CasChem are the largest U.S. importers.

A total dependence on imported castor oil leaves the United States in a vulnerable position should the supply be interrupted because of world events. An irrigated domestic crop would give users a stable source of supply. To replace imports, the United States would need about 100,000 acres of castor to supply domestic users.

Figure 6.
U.S. Imports of Castor Oil, 1960-89.



Source: [20].

Castor has been grown commercially in many States west of the Mississippi River. However, current interest is focused on the High Plains of Texas. Therefore, discussions of crop production and economics concentrated on this region.

Plant Characteristics

Castor is a member of the spurge family *Euphorbiaceae*. The scientific name is *Ricinus communis* L. [18]. Most authorities consider castor to be native to eastern Africa [5]. Around the world, castor and its oil have many common names such as mole bean, Ricinus Oil, oil of Palma Christi, tangantangan oil, and Neoloid [14, 21]. However, castor is not a legume and should not be referred to as a bean [13].

In the Tropics, castor grows as a perennial, reaching heights of 30 to 40 feet. In temperate climates, it is an annual crop. Improved varieties grown in the United States have ranged from 10 to 12 feet in height down to 4 to 6 feet for dwarf-internode varieties. For mechanical harvesting, plants shorter than 6 feet are desirable.

The castor plant has a tap root supplemented with prominent lateral roots a few inches below the soil surface. Researchers have reported tap roots of 4 to 6 feet. Long tap roots have also been found under field conditions; a former grower at the workshop described digging a plant with a tap root of over 4 feet.

The long tap root accounts for the plant's ability to withstand drought. The tap root also is credited with breaking claypans and allowing water to penetrate more readily into the subsoil, as well as improving soil tilth. Some agronomists and farmers attribute the higher than normal yields of crops following castor to these characteristics; however, this has not been scientifically proven.

The castor stalk is strong and branched with large, lobed leaves. Each successive branch terminates with a seed spike, technically a raceme, with seed capsules. This sequential growth results in continuous seed formation; earlier spikes mature while later ones are still developing.

Castor has separate male and female flowers on the seed spike. Neither type of flower has petals. Plants are both self and cross pollinated. Pollen is carried from the male flowers to the female flowers primarily by the wind. The fertilized female flowers develop into seeds inside capsules, which usually possess spines. Capsules typically contain three seeds.

Capsules of wild castor plants tend to shatter as a mechanism to scatter seed and reproduce. However, present commercial varieties and hybrids grown for mechanical harvest hold their seed within the capsule for several weeks after a killing frost with no appreciable seed loss [5, 18].

A pound of castor typically contains 1,400 to 1,600 seeds. The oil accounts for 50 percent of the seed on a dry-weight basis [14]. The seed coat represents about 25 percent.

> WARNING: The seed, leaves, and stem of castor are POISONOUS TO HUMANS AND LIVESTOCK if consumed [4]. Eating even one seed can be fatal to humans [14]. Ricin, a very lethal protein, is the major toxic component. Ricinine, a poisonous alkaloid, exists at very low levels and presents little problem [22]. Care must be taken to educate individuals on the poisonous nature of castor.
>
> In addition, castor contains a very potent allergen known as CB-1A (a protein polysaccharide). Some individuals are very sensitive to this allergen upon first exposure. For others, an allergic reaction may occur with prolonged exposure.

Growing Castor on the Texas High Plains

The High Plains of Texas are well suited to castor production. Castor grows well on silty clay loams (medium-textured soils) when irrigated [5]. Most local soils do not contain enough salt to pose problems to castor's low alkaline tolerance. Low relative humidity provides an environment that deters serious capsule mold, a major problem in humid environments.

Castor plants are reasonably tolerant to hail damage. They recover from early hail damage better than most other crops because of their branching growth habit. However, late season hail, which seldom occurs in the High Plains, can knock capsules off the plant.

One reason for farmer interest in growing castor is that, except for planting and harvesting equipment, cultural practices are similar to cotton, corn, and sorghum—major crops produced in the High Plains. This means that farmers can use existing production methods and equipment.

Dr. Ray Brigham shows participants a castor capsule, which normally contains three seeds. The fabric of his necktie is made of castor oil polymers and has a design of castor leaves.

Seed Supply. At present, the only available commercial seed supply is open pollinated varieties. Over the past two decades when castor was not grown in the United States, hybrid seed was not maintained. Therefore, no commercial supply of hybrid seed exists today.

However, because of Browning Seed's efforts in seed development, the quantity and quality are being improved. They planted several hundred acres of open pollinated varieties in 1990. This will provide seed for 30,000 to 35,000 acres of commercial production. Hybrids are expected to be available within 2 to 3 years. Castor hybrids have better germination and vigor, but not the major yield increases experienced in some other crops [18].

Excellent opportunities exist for further plant improvements. Germplasm at the USDA Southern Regional Plant Introduction Center in Georgia and National Seed Storage Laboratory in Colorado, as well as from other sources, needs to be investigated. However, the small quantities of seed stored at the USDA facilities likely have very low germination. Although castor seed does remain viable for 8 to 10 years at room temperature and 10 to 15 years in cold storage, the viability of the seed and vigor of the seedlings may have declined.

Planting. Castor is planted in the High Plains in late April or early May, typically after corn but before cotton and sorghum. Special planter plates are required to handle the large, fragile seed. In fact, air planters are best for planting castor. They handle the seed without damage, accurately place them in rows, and allow faster ground speeds, thereby reducing time and saving money.

Ten to fifteen pounds of seed is needed per acre to get a good stand of castor, depending on germination rates and desired population levels. This typically produces about 13,000 plants per acre, with 1 foot between plants in 38- or 40-inch rows. Row width must be consistent with harvesting equipment.

Castor seed is planted about 2 to 3 inches deep in ridges or beds once the soil temperature has reached 60°F. It generally takes about 2 weeks for castor seedlings to emerge. Seed should be treated with a fungicide to prevent damping off if the weather turns cool and wet at planting time. Castor is less prone to damping off than is cotton.

Since castor plants continually set seed, longer growing seasons are advantageous. Generally, a growing season of 140 days from planting until a killing frost is required to achieve satisfactory yields in the Texas High Plains. Hence, castor should not be planted in the area after June 20, since frost often occurs there in early November.

Fertilizer. Nutrient requirements for castor are similar to those for sorghum. Fertilizer studies were conducted for the High Plains when castor was produced there [23, 24].

For castor, adequate amounts of nitrogen and phosphorous are needed for high yields. All fertilizer applications should be based on soil analysis and farmer experience. In nitrogen-deficient fields, from 60 to 120 pounds of nitrogen per acre may be needed for optimum yields. However, it is possible to overfertilize with nitrogen, resulting in too much vegetative growth and not enough additional yield to pay for the extra fertilizer. In fields where other crops respond to phosphorus, farmers should apply 30 to 60 pounds of phosphoric acid equivalent per acre for castor.

Pests. Castor competes well with weeds once the leaves begin to shade the rows. However, because seedlings are slow to emerge, early weeds and grasses pose a problem, and they must be controlled with either cultivation or herbicides. Efforts are underway to get the herbicide Prowl approved for use in castor. Experiments have shown that Treflan and other herbicides used in cotton also are effective for controlling weeds in castor.

Castor is sensitive to chemicals often used for crops such as corn, sorghum, cotton, and soybeans. Drift from applications on nearby fields can destroy castor. Farmers also need to be cautious in field selection, because residual chemicals from previous crops can cause serious damage to castor.

Jeane Browning with a field of young castor plants. His firm has been instrumental in increasing the seed supply of castor.

Castor appears to have an allelopathic impact on nematodes, as does the meal if used as a fertilizer. This may account for farmers reporting higher yields of other crops following production of castor.

In the High Plains, the primary disease of castor is capsule mold. It occurs each year in varying degrees, even with the area's low humidity and high summer temperatures. Unless unusually moist and cool conditions persist for extended periods, capsule mold is not a serious problem. Because no effective treatment exists for capsule mold, the High Plains have an advantage over more humid areas in growing castor.

Soils infested with cotton root rot fungus should not be planted to castor, since the plants are highly susceptible to this disease. Infested soils do not occur on the High Plains but are found on the nearby Rolling Plains and extend to east Texas and the gulf coast. Again, no effective treatment exists for cotton root rot.

False chinch bugs occur periodically, but seldom do the infestations become serious enough to warrant control. If so, Parathion is an effective treatment. However, it is currently not approved for use in castor.

Irrigation. High yields of castor in the High Plains require irrigation. Castor needs about the same amount of water as sorghum, less than corn, but more than cotton.

Generally, farmers water a field once before planting and two to four times during the summer, depending on temperature, moisture, wind, and soil conditions, as well as the desired yield. Castor does not like "wet feet," therefore it should not be overwatered.

Capsule mold may be a problem with traditional center-pivot irrigation because the water is sprayed on the entire plant, creating an area of high humidity around the capsules. The LEPA (low energy, precise application) center-pivot system could be an excellent alternative for irrigating castor because the water can be directed below the plant canopy, missing the capsules. The precise application reduces puddling in the furrows and the amount of water applied.

Harvesting. Under favorable conditions, castor is harvested 10 to 12 days after a killing frost, which typically occurs in early November in the High

Plains. Corn and sorghum are harvested before castor. Cotton is harvested at about the same time but requires different machinery. Like cotton, castor often would be custom harvested.

Special equipment is required to harvest castor. Presently, no equipment manufacturer produces a castor harvester. In the 1950s and 1960s, John Deere 55 combines were modified to harvest castor in the High Plains. However, many problems existed with these 2-row machines. Hand harvest is practiced in many developing countries, but would be prohibitively expensive in the United States.

Browning Seed, in conjunction with a local machine shop, has developed an improved harvester-huller for castor. The machine successfully harvested seed-increase acreage in 1989. Some modifications were made in the machine based on that experience.

This harvester-huller appears to be a significant advancement in mechanical harvesting, thus overcoming a major barrier to a successful domestic castor industry. Brushes on the 4-row header gently and efficiently strip capsules from the plant. The seed is then removed from the capsules in the machine's modified thrashing unit. Heat from the engine is used to warm augers to prevent oil and debris from thickening and clogging them. Ground speed of the equipment is 4 to 5 miles per hour, much faster than the old John Deere units. Browning Seed is patenting these machines and will make them available for custom harvesting.

Seed loss at harvest is a concern. As with any crop, a small percentage of the seed passes through the machine and is discharged with plant residues onto the field. These seeds will come up next spring as volunteer plants [25, 26, 27]. Because of castor seeds' toxicity, plants must be removed before food or feed crops are harvested. The herbicide Roundup applied by ropes or wicks is an effective method of killing volunteer castor plants, which are often taller than the surrounding crop. Cultivating and hoeing are other options. Anyone harvesting another crop should stop and carefully remove volunteer plants before continuing. A load of grain can be condemned because of a few castor seeds. In fact, grain facilities can be shut down if castor seed is found in the grain.

Advice Program. During the workshop, participants discussed methods to provide farmers with information on growing and harvesting castor. This could include workshops prior to planting, on-farm visits, or other methods. The successful advice program offered by American Seed Company, a Division of Calgene, Inc., for industrial rapeseed was cited as an example. Company representatives assist in selecting fields, testing soils, calibrating planters, monitoring fields on a monthly basis, determining when to begin harvest, and calibrating harvesting equipment. With castor, advice for appropriate handling and storage of toxic seed, recognition of allergy symptoms, and proper timing of irrigation also should be considered.

Income and Costs

An experienced consultant conducted a study for Browning Seed, Inc., comparing the net income farmers could receive in 1990 for castor, corn, cotton, sorghum, soybeans, and wheat in the High Plains [28]. The results indicate that castor would have been profitable for growers. Net income from castor ranged from $5 to $93 more per acre than the returns from the other crops (table 1).

Texas Agricultural Extension Service budgets were used to estimate income and costs for the various crops except castor. The consultant developed a budget for castor consistent with those for the other crops. The cost estimates include operating expenses plus interest, custom harvesting and hauling charges, and fixed costs on machinery and land.

The consultant used yields for castor that a good manager could achieve. The estimated price of castor seed, containing 50 percent oil and delivered to the crushing plant, was set at 15 cents per pound.

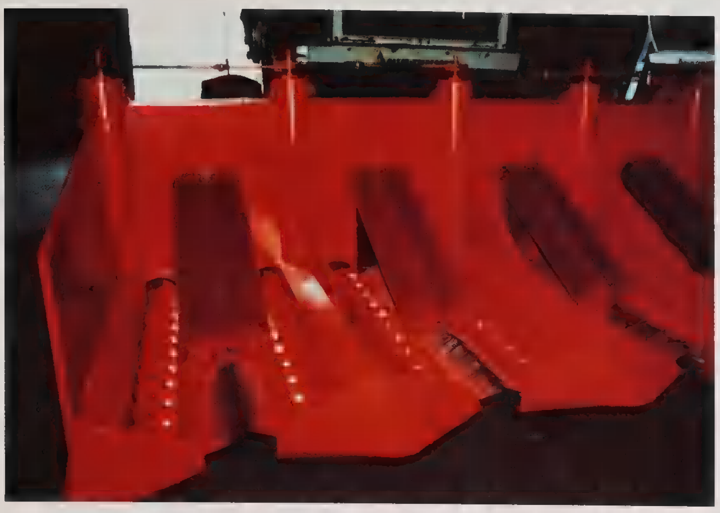
Deficiency payments were included in the income for corn, cotton, sorghum, and wheat. The amounts reflect maximum payment rates with no payment limit. (Farmers participating in Federal support programs for these crops sometimes receive deficiency payments when market prices are lower than specified target levels.) Without deficiency payments, castor would have been even more profitable compared with the other crops.

In the workshop, participants noted several factors that further enhanced castor's attractiveness:

- Average cotton farms in the area quickly reach the $50,000 limit on deficiency payments.

- The 1990 Farm Bill alters support programs for traditional commodities such as corn, sorghum, cotton, and wheat, the main crops of the High Plains. The added planting flexibility may allow farmers to grow castor without losing program acreage.

The consultant also analyzed the impact on net income of various castor yields (1,500 to 4,000 pounds per acre) and oil content of the seed (47 to 52 per-



Brushes that remove capsules from the plant are a major advancement in mechanized castor harvesting.

cent). With 52 percent oil content, a farmer would need a yield of 2,200 pounds to break even. With 47 percent, 2,400 pounds would be necessary.

Production Contracts

Browning Seed, or its subsidiary Castor Oil, Inc., may offer production contracts to farmers in 1991. These contracts will be backed by an agreement from users to purchase castor oil at a predetermined price. Tentatively, Browning Seed is considering a contract price with farmers of about 15 cents per pound for seed. Adjustments in the price will be made for oil content different than 50 percent, moisture above 6 percent, and any foreign material.

Farmers participating in the workshop voiced preference for multiyear production contracts. Such agreements would demonstrate industry commitment to a long-term partnership. This would benefit both parties in planning and may be crucial in reestablishing domestic production.

The leadership provided by the private sector on this issue is commendable. However, questions remain. What constitutes an equitable multiyear contract for both producers and buyers, given changing economic conditions? Who will provide bridge financing from the time the crop is harvested until the oil is sold? Some mechanism is needed to provide funds to pay farmers upon receipt of the seed, although it is not yet crushed and the oil sold. This lack of financing is a serious impediment and needs to be resolved. Workshop participants suggested Government assistance in identifying such financing.

Table 1. Income and Costs for Castor and the Major Crops of the Texas High Plains, 1990.

Crop	Unit	Yield per acre	Price per unit	Total income[1]	Cost per acre	Profit or (loss)	Advantage of castor
			Dollars				
Castor	pound	2,200	0.15	330.00	327.30[2]	2.70	--
		2,500[3]	.15	375.00	327.30[2]	47.70	base
		3,000	.15	450.00	329.80[2]	120.20	--
Corn	bushel	140	2.50	382.20	438.44	(56.24)	103.94
		175	2.50	469.70	448.24	21.46	26.24
Cotton	pound	550	.56	435.05	392.31	42.74	4.96
Sorghum	hundredweight	60	3.93	278.40	297.99	(19.59)	67.29
Soybeans	bushel	45	5.35	240.75	286.04	(45.29)	92.99
Wheat	bushel	60	3.06	261.00	273.89	(12.89)	60.59

-- = Not applicable.

[1]Includes deficiency payments of 23 cents per bushel for corn, 15 cents per pound for cotton, 71 cents per hundredweight for sorghum, and 89 cents per bushel for wheat. Wheat income also contains $24 per acre from grazing.

[2]Cost estimates for castor are based upon sorghum cultural practices, including irrigation and fertilizer, with increased costs for seed and harvesting.

[3]Yield used in comparing returns from castor with those of other crops.

Source: [28].

Research and Development Needs

Workshop participants were asked to identify barriers that would impede sustained castor production in the Texas High Plains. Industry has initiated efforts to address hindrances and has made excellent strides in restoring seed supply and developing mechanical harvesters. However, participants identified other areas where additional research and development are warranted.

Research on various aspects of castor production has been nearly nonexistent over the past two decades. This means that the United States has lost ground to other countries in castor development. Moreover, the research conducted in other parts of the world may not be transferrable to U.S. conditions. For example, varieties developed in Costa Rica grow 8 to 12 feet tall and are therefore not amenable to mechanical harvest. These varieties also are very late blooming, a characteristic ill-suited to the shorter growing season of the High Plains.

The diversity in castor germplasm offers opportunity to improve the crop through plant breeding and selection. These activities should focus on priorities such as higher yields, increased oil content, greater insect and disease resistance, improved drought tolerance, and shatter resistance.

Only a few plant breeders in the United States have experience with castor, and currently they are involved with other crops. Workshop participants knew of no graduate students working on castor. In fact, few people with production experience are available to advise farmers on growing castor.

Another agronomic factor that needs to be addressed is pest control—both weeds and insects. Weed control should include both mechanical and chemical means. While insects are not usually a major problem, chemical control is sometimes necessary. A broader array of pesticides needs to be approved for castor.

Castor seed is toxic and may contaminate a future crop. More cost effective and environmentally friendly methods than manual removal or existing chemical control to remove volunteer plants may help farmers with crop management.

Creative business and marketing alternatives are needed for castor and other industrial crops. Innovative methods should be developed for financing annual operating costs, providing equitable long-term contracts to share risks and returns, and paying farmers for the seed when the oil and meal will be sold months later. Better information on domestic and foreign costs of production will help farmers and buyers reach agreement on contractual terms.

Innovative techniques are needed to communicate and educate local, State, and national leaders. New crops often are met with skepticism. For example, farmers may have difficulty obtaining financing from local bankers. With improved communication, Government officials may be willing to alter programs, changing provisions that put new crops at a disadvantage.

Oil is the primary product of castor. The seed contains 45 to 55 percent on a dry-weight basis. In the past, commercial plants have been able to recover about 92 percent of the oil.

Meal is another product of crushing oilseeds. In the past, castor meal has been used as a fertilizer or a feed ingredient for cattle. The meal commands a higher price when sold as feed, but it is cheaper than soybean meal, primarily because of nutritional differences. Finding high-value markets for castor meal will be crucial to the success of a crushing operation.

Storage and Handling

No special equipment is needed to haul or store castor seed. Insects and rodents avoid it because of the toxins.

Special conveyors are needed in the processing plant to move castor seed. Traditional augers tend to press oil out of the soft seeds, resulting in accumulations of oily debris that clog the equipment. Hence, drag or belt conveyers are preferred.

A major consideration with handling castor in the crushing plant is the toxins and allergen in the seed and meal. These compounds remain in the meal after the oil is removed. Ricin is easily destroyed by heat and can be inactivated by adding steam after evaporating the solvent from the meal [22].

The allergen poses the greatest concern in processing. Typically, allergen levels range from 6 to 9 percent in castor seed and 1 to 4 percent in untreated meal [29]. A few cases have been reported where individuals could not live in areas where castor was processed.

It might be valuable to test people for an allergic reaction to castor prior to hiring for positions at a processing plant. Care should be exercised in the plant to control dust from castor seed or meal. Special dust control equipment may be warranted. Involuntary exposure of individuals to the dust may pose more problems than voluntary exposure by workers.

No special equipment is needed to haul or store castor seed.

Oil Removal

Four primary methods exist to remove oil from oilseeds: screw press, solvent extraction, prepress-solvent extraction, or extrusion followed by solvent extraction. Hexane is the usual solvent. Historically, crushers have favored prepress-solvent extraction, but extruders are increasingly popular.

Removing the oil from castor seed is relatively straightforward using prepress-solvent extraction. Prepressing is typical for oilseeds containing high amounts of oil. Expellers (screw presses) are used to remove some oil. The remainder is then extracted using solvents.

Increasingly, oilseed crushing plants are substituting extruders (these machines are also called expanders) for expellers to prepare seed for solvent extraction. They pressurize the seeds into a paste-like mixture. Upon release, the material rapidly expands and dries. The resulting collets or pellets are very porous, which allows faster solvent penetration. The material contains very few fine particles that impede solvent flow. Due to their greater extraction efficiency, extruders generally pay for themselves within 6 months.

Extruders have not been commercially tested with castor seed in the United States. Preliminary pilot-scale studies were conducted at Texas A&M University, with positive results.

Meal Processing and Use

An extrusion process has been developed by Dr. K.C. Rhee of Texas A&M University to detoxify and deallergenate castor meal [22, 29]. This can occur only after the oil is removed, because of the oil's sensitivity to high temperatures.

The meal is thoroughly mixed with alkaline chemicals, such as sodium hydroxide, lime, and sodium hypochlorite. The mixture is then heated in an extruder to 300°F. The combination of heat and chemicals is the key to deallergenating the meal. Similar processing has been used to destroy aflatoxin in peanuts.

The research and development that led to this process was sponsored by the United Nations Industrial Development Organization (UNIDO), with major support from France and Germany. UNIDO required this continuous process not be patented, so that it could be used in feed-deficient, Third World countries without obstacles.

As a result of Dr. Rhee's work, a plant in Thailand is successfully using the detoxification and deallergenation process to treat 3 metric tons of meal per hour. Allergen levels drop to practically zero.

Castor meal has about 35 percent protein [14]. As a rule of thumb, each percent protein from an oilseed meal is worth roughly $4 per ton. However, this may be high for castor. The lysine and methionine values are low—5.5 to 6 percent and 0.7 to 0.8 percent, respectively—relative to traditional protein sources used in livestock rations. The deallergenation process lowers the methionine value even further.

In addition, castor meal has a high level of abrasive fiber, about 30 percent. Because of its amino acid and fiber content, treated meal may be used with other protein sources in cattle rations. The fiber can also be inexpensively removed, making the meal suitable for other livestock.

Reportedly, treated castor meal that is produced in Texas could be fed to cattle locally. Sufficient cattle are raised in the High Plains to use the meal from a castor processing plant. During the 1960s and 1970s, when castor was grown and processed in the State, detoxified meal was fed to cattle in the area [13].

Meal entering interstate commerce would require Food and Drug Administration (FDA) approval as a feed ingredient. No obvious reasons exist why the meal would not meet FDA requirements. However, the necessary tests are both costly and lengthy.

FDA requires animal feeding trials comparing castor meal with a standard ration. This generally entails feeding two animal species—hogs and cattle, for example—in two different replications. The process could take up to 4 years using approved procedures.

Many successful feeding trials have been conducted with cattle in the past, including some at Texas A&M University [29]. However, workshop participants were concerned that these trials might not meet current FDA requirements.

The traditional use of castor meal is as a fertilizer. It has been used successfully in California and Florida citrus groves and in U.S. tobacco fields. Japan and other countries also utilize the meal as fertilizer. However, fertilizer is a relatively low-value use. Moreover, dust from fertilizer applications could pose problems if the meal is not deallergenated.

Texas Processing Plant

Negotiations are underway with major oil seed processor to crush castor seed grown in the High Plains. The plant under consideration was built in 1962, in

Plainview, Texas, to process castor. The mill has been mothballed for some years and would need modernization. An extruder might be worth considering before changes are made. Workshop participants suggested that testing procedures be developed to monitor allergen levels in and around the plant. The potential crusher reportedly is reviewing Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA) regulations to ensure compliance. Thorough and effective management and control of the operation will be required to guard the health and safety of workers and the surrounding community from the toxins and allergen.

Current plans call for the plant to be dedicated solely to processing castor seed. Initially, the amount of seed harvested in the High Plains will only keep it operating for part of the year. The crusher may want to import seed to keep the plant running for a longer period, thereby reducing fixed costs per unit processed.

Research and Development Needs

A small, highly focused research effort could provide answers to most of the concerns about processing and meal uses that were voiced at the workshop. However, little research and development has been conducted in recent years on castor processing, other than the UN-sponsored detoxification and deallergenation work. From the 1950s until the early 1970s, ARS's Western Regional Research Center had a productive research program on meal processing, including work on the allergen [29, 30].

Work needs to be undertaken to commercially test the use of extruders. These machines may increase oil recovery and improve efficiency. Also, a reliable method for determining allergen levels in the air and in the meal could be very helpful.

Care should be exercised to assure the processing plant's competitive position in the market. One option would be to explore importing castor seed to lengthen the crushing season.

Feeding trials would be worthwhile to determine the meal's value in livestock rations. Also, the meal would need to meet FDA requirements before it could enter interstate commerce. High-value uses for the meal need to be found, since this appears to be a key to long-term profitability for a domestic industry.

• • Oil Characteristics • •

Castor oil is pale yellow and viscous with a slight characteristic odor. It tastes slightly acrid with a decidedly nauseating aftertaste, which many remember from its use as a mild purgative [31].

Among commercial vegetable and petroleum oils, castor oil is in a class by itself. Its unique fatty acid content and chemical structure make it highly valued for industrial uses [30, 32].

Like other vegetable oils, castor oil is made up of various fatty acids. However, the oil is highly unusual in that its fatty acid profile is dominated by one type of fatty acid—ricinoleic acid (table 2). Castor oil is one of the few naturally occurring glycerides that approaches being a pure compound [14].

Users also consider castor oil to be very uniform. No matter where the seed is grown or how it is processed, the oil has a consistent chemical composition [14, 32].

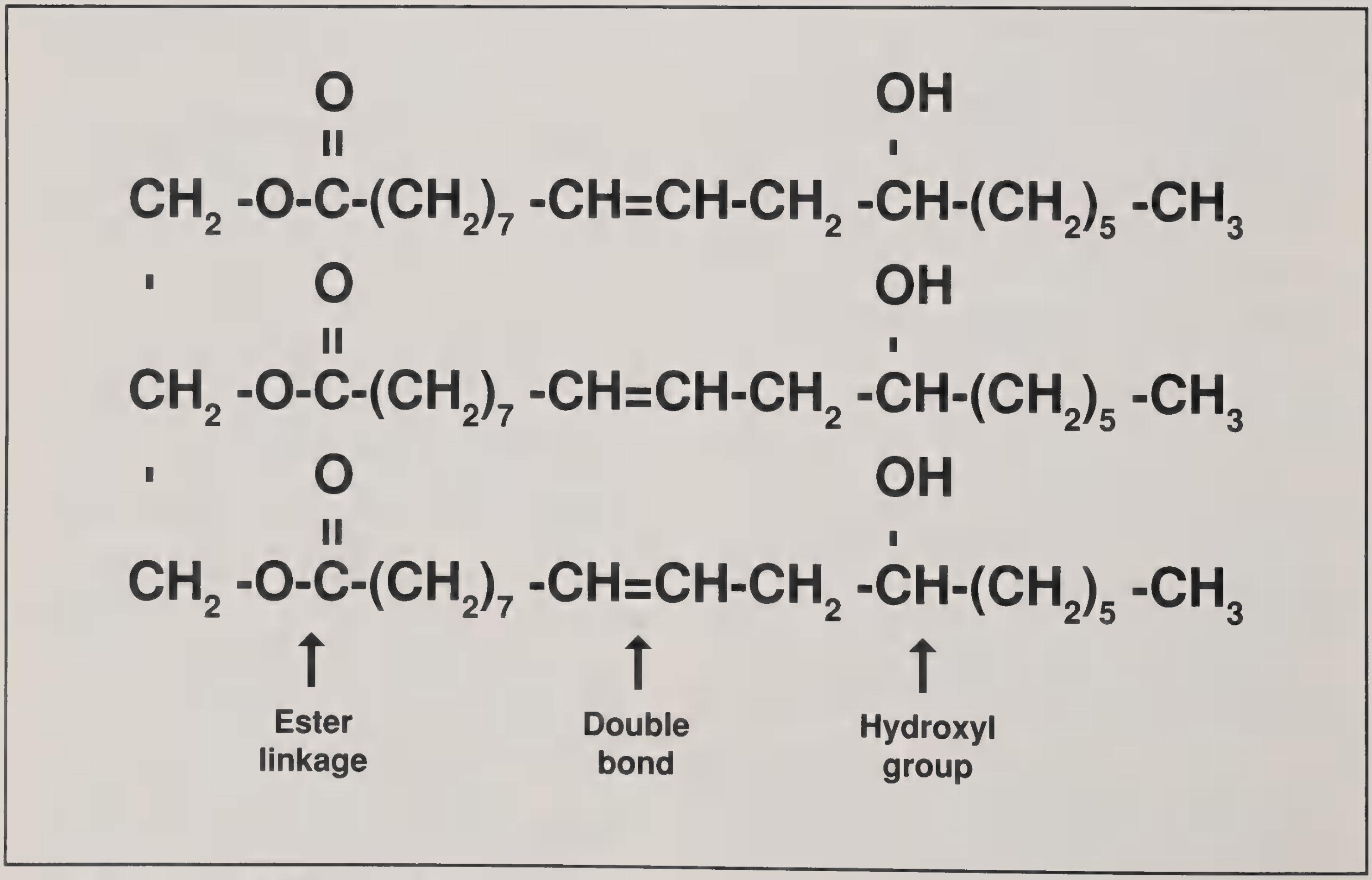
Table 2. Fatty Acid Composition of Castor Oil.

Fatty acid	Percent
Ricinoleic acid	89.5
Linoleic acid	4.2
Oleic acid	3.0
Palmitic acid	1.0
Stearic acid	1.0
Dihydroxystearic acid	0.7
Eicosanoic acid	0.3
Linolenic acid	0.3

Source: [14].

Other characteristics unique to castor oil are due to its chemical structure (figure 7). It is the only commercial source of a fatty acid–ricinoleic–that has a hydroxyl group (the oxygen and hydrogen attached to the 12th carbon) and a double bond [32].

Figure 7.
Chemical Structure of Castor Oil.



The three 18-carbon chains are ricinoleic acid.

The hydroxyl groups give the oil its unusual physical characteristics. It is a stable compound and has a high viscosity, which means it is thick like honey. Castor oil maintains its viscosity over a wide range of conditions, unlike other oils that thin out at high temperatures or solidify in low temperatures. The oil also possesses very good oxidative stability.

Because of the hydroxyl group, castor oil is soluble in alcohols in any proportion, yet has only limited solubility in petroleum solvents. The combination of a hydroxyl group with a long chain fatty acid and double bond makes the oil compatible with a wide range of natural and synthetic resins, waxes, and polymers.

Castor oil, at 8 pounds per gallon, weighs about the same as water. It also has a flash point of 445^{0}F, an iodine number of 81 to 91, and a hydroxyl value of 161 to 169. Ricinoleic acid (technically, 12-hydroxy-9-octadecenoic acid) has a molecular weight of 298.47, a boiling point of 440^{0}F, and a density of 0.9450 [31, 33].

Castor oil derivatives are made using the three reactive sites in the molecule: the hydroxyl group, double bond, and ester linkage (the carbon and two oxygen atoms) [32]. Because of these components, the oil is used as a raw material in a wide range of chemical reactions. The resulting derivatives are contained in numerous products, from lipstick to jet-engine lubricants.

Castor seed contains a pale yellow oil valued by industry for its chemical properties.

• • Uses of Castor Oil • •

Castor oil is one of the oldest industrial products from agriculture. Castor seeds have been found in Egyptian tombs dating back 4,000 years. Egyptians of those days used castor oil in their lamps [5].

In modern times, castor oil and its derivatives have been used in lubricating formulations. Its unique properties make it invaluable for military purposes. The hydrogenated oil imparts thickening properties in grease formulations and sebacic acid serves as a lubricant in jet fuels and aircraft hydraulics. Because of these uses, DOD continues to include ricinoleic and sebacic acid products on its list of critical and strategic materials. DOD's inventory is 5 million pounds, about 55 percent of the target level [34]. (See Appendix E for information on DOD's strategic and critical materials program.)

Industry has developed many new products that contain castor oil or its derivatives, such as nylon, weather-resistant paints, and cosmetics. Many firms are active in manufacturing or selling castor products (table 3). The major uses of castor oil, listed in order of importance, are: nylon-11, hydrogenated oil, dehydrated oil and its fatty acids, sulfated and sulfonated oil, sebacic acid, ethoxylated oil, polyurethanes, and oxidized and polymerized oil. (A forthcoming report from the International Castor Oil Association will give details on the varied uses of castor oil.) The use of castor oil as a laxative has declined throughout the years and is now of minor importance [18].

Castor oil and its derivatives are contained in a wide range of products.

Direct Uses

The oil often is used directly in products. It has excellent emolliency, which means it feels soft and soothing when applied to the skin. Therefore, it is used in a wide range of cosmetics and toiletries. In addition, the oil is noncommunogenic—it does not promote the growth of the bacteria that causes acne. Castor oil is a key ingredient in transparent soaps that are gentle to the skin.

Food-grade castor oil is a standard lubricant in food-processing plants. Its uses range from an antistick agent in candy molds to a lubricant for trolleys and conveyors that carry food [32].

Castor oil is used in numerous applications for its ability to plasticize resins and polymers, making them more pliable and elastic. Examples include natural and synthetic rubber, waxes and polishes, sealants, and inks. Castor oil also is used in adhesives, like those for artificial turf at sports stadiums and parks. As a lubricant, the oil is used in metal drawing oils, two-cycle engine oils, and high-temperature aluminum-casting release agents.

Castor Oil Derivatives

Castor oil derivatives are used in many different ways. Some of the main products are listed by chemical reaction in the following discussion.

Products Derived From Hydroxyl Group. Dehydration removes the hydroxyl group and a nearby hydrogen atom, adding a double bond to the carbon chain. This converts castor oil into an excellent drying oil, which is used extensively by the coatings industry. Commercial applications became significant during World War II as a replacement for tung oil. Present uses include primers, topcoats, binders, caulks, and sealants [32].

Table 3. Major U.S. Suppliers of Castor Oil and Derivatives.

Supplier	Product
Acme Hardestry Company, Inc.	Hydrogenated oil
Akzo Chemical Division	Hydrogenated oil
Alnor Oil Company, Inc.	Oil, blown oil, dehydrated oil, hydrogenated oil
Amber Company, Inc.	Oil, hydrogenated oil
Atlas Refinery, Inc.	Sulfated oil, sulfonated oil
CasChem, Inc.	Oil, dehydrated oil, oil esters, hydrogenated oil, fatty acids, dehydrated fatty acids, hydrogenated fatty acids
Ethox Chemicals, Inc.	Ethoxylated oil
Finetex, Inc.	Sulfonated oil
Heterene Chemical Company, Inc.	Ethoxylated oil
High Point Chemical Corporation	Sulfated oil
Laurel Products Corporation	Sulfonated oil
Lonza, Inc.	Oil esters
Mazer Chemicals, PPG Chemicals Group Division	Ethoxylated oil
Polyesther Corporation	Oil esters, hydrogenated oil
Quantum Chemical Corporation, Emery Division	Sulfonated oil, ethoxylated oil, fatty acids
Union Camp Corporation, Chemical Products Division	Oil, hydrogenated oil, oxidized oil, sulfonated oil, sebacic acid, esters
United Catalysts, Inc.	Oil, sulfonated oil, hydrogenated oil

Source: [8, 35].

Sulfonation results when concentrated sulfuric acid is added to castor oil under the appropriate conditions. The reaction yields Turkey Red oil. This water-soluble compound is one of the earliest castor oil derivatives, which is used in dyeing and finishing textiles [13, 14].

Alkali fusion is used to obtain sebacic acid. This derivative is employed in manufacturing nylon-610 and jet-engine lubricants.

Ethoxylated derivatives of castor oil help solubilize water-insoluble chemicals. Therefore, they are ingredients in cosmetics, detergents, lubricating and cutting oils, hydraulic fluids, textile-finishing compounds, and antistatic agents [14].

Urethane polymers result from the reaction of the hydroxyl groups with chemicals containing isocyanate groups. These polyurethanes are widely used in telecommunication and electrical materials, biomedical and industrial filters, and coatings.

Products Derived From the Double Bond. Hydrogenation of castor oil means adding hydrogen to the double bonds, which results in a hard, brittle wax. Hydroxy castor waxes are used in metal drawing lubricants, processing aids for rubber and plastics, strippable coatings, pencils and crayons, cosmetics and toiletries, and electrical-potting compounds, as well as a substitute for carnauba wax. Hydroxyamide waxes are used in the manufacture of release agents in plastic extrusion, antistatic agents,

antiblock agents, and binder lubricants for powdered metals [32].

Oxidized (blown) castor oil is formed by adding oxygen or air. The oil is used as a plasticizer in resins, coatings, plastics, inks, adhesives, and numerous other products [14].

Products Derived From the Ester Linkage. Esterification of ricinoleic acid results in methyl ricinoleate, the feedstock in the manufacture of nylon-11. The French manufacturer Atochem, Inc., produces nylon-11 under the trade name Rilsan. The company uses roughly one-third of the castor oil traded in world markets. The monomer is made in France and then some is shipped to the United States, where it is made into Rilsan. This nylon product has low-water uptake and good dimensional stability relative to most other nylons, as well as excellent high and low temperature characteristics, good tensile strength, and resistance to chemicals. Thus, it is used in products—like gears, tubing, and coatings—where friction or extreme temperatures are involved. For example, some critical automotive and aircraft components contain Rilsan.

Castor oil fatty acids are used in cutting oils, industrial lubricants, transparent-bar soaps, heavy-duty detergents, inks, coatings, plastics, industrial fungicides and bactericides. The largest use for hydrogenated castor acids is in the manufacture of lubricating greases. Dehydrated fatty acids are the basis for additional products. These include coil and tube coatings, automotive primer and finish coatings, maintenance primers and topcoats, coatings for food and beverages containers, and high-speed printing inks.

Research and Development Needs

Expanding the use of castor oil will require research and development. Industry representatives at the workshop expressed a desire to work with academia and government in this effort. It typically takes a minimum of 5 years to develop and introduce a new product into the market.

Some potential areas for expansion include: adhesives and sealants, agricultural and oil-field chemicals, cosmetics, electronics, germicides and algicides for aquaculture, industrial coatings, inks, interpenetrating polymers, plastic additives, rubber, specialty lubricants, specialty pharmaceuticals, surfactants, and textile processing.

Once castor oil prices stabilize and new products are created, more market development may be a next step.

• • Conclusions and Recommendations • •

The private sector has made major strides in the last few years that should serve as a solid foundation for domestic castor production. Browning Seed, Inc., began a program of seed multiplication and improve ment. With support from Union Camp Corporation and CasChem, Inc., Browning Seed developed and tested, and now is patenting, a harvester-huller. It may offer farmers contracts for commercial production in 1991 with a target of 35,000 acres. Negotiations are underway for an oilseed crusher to process the crop.

As the last item on the agenda, workshop participants developed recommendations to advance domestic production and processing of castor. No insurmountable barriers surfaced in the discussions. Yet, participants suggested several activities that would complement existing industry efforts. The group highlighted the following areas for attention. The recommendations are listed beginning with those related to production and ending with uses.

- A crop improvement program involving the private and public sectors is needed to develop improved varieties with higher yields, greater oil content, increased resistance to capsule mold, and other desirable properties.

- Approval of pesticides for use on castor would help farmers in their control of weeds and insects. Further research on capsule mold would also be useful.

- Flexibility in USDA commodity programs would be beneficial for farmers wanting to grow nontraditional crops like castor. In the past, many felt constrained by base-acreage requirements for program crops. Some workshop participants expressed the desire for assurances that program "rules" would not change, as has occurred in the past.

- A program to educate growers and provide technical support is needed.

- Three-to-5-year contracts for farmers can provide production stability. Thereby, industry and farmers would share the risks of fluctuating world prices and supplies.

- Bridge financing is needed so farmers can be paid at harvest while the oil is sold throughout the year.

- Industry may want to validate the use of extruders in processing castor seed. Development of in-plant systems to monitor allergen levels would also be advantageous.

- Feeding trials are needed to determine the value of castor meal in livestock rations. The information gained will be used in applying for FDA approval of castor meal as a feed ingredient sold in interstate commerce, although large market potential exists in Texas.

- Workshop participants from the private sector expressed the desire for a "roadmap" that would help businesses in complying with Government regulations when commercializing new industrial products. The guidelines could be developed jointly by EPA, FDA, OSHA, and USDA. Entrepreneurs could use such a document as a resource in gathering information on Federal Government regulations.

- Stable castor oil prices would help curtail loss of markets. Furthermore, price stability would foster investment in new research and market expansion.

- Development of new castor oil derivatives and applications is needed. This work could be undertaken by private industry in cooperation with ARS regional laboratories and universities.

Working with industry, both the State of Texas and USDA can make significant contributions in fostering domestic castor production. Since castor oil provides critical and strategic materials, public sector support is particularly relevant. Such private-public cooperation appears to be consistent with provisions contained in the 1990 Food, Agriculture, Conservation, and Trade Act to encourage commercialization of industrial products from agricultural materials [10].

• • References • •

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• • Appendix A • •

Castor Workshop Participants

September 18-19, 1990
Plainview, Texas

Mr. John C. Anderson
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Plainview, Texas

Mr. Bob Benson
Hale County Extension Agent
Plainview, Texas

Mr. Wayne L. Board
SW Farm Press
Lubbock, Texas

Mr. R.T. Bothwell
Plainview, Texas

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Mr. Lee Browning
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Dr. Kenneth D. Carlson
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Peoria, Illinois

Ms. Lewrene K. Glaser
USDA-ERS
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Harp Agri-Management Services
Abernathy, Texas

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R.S. Hawkins, Inc.
Wyckoff, New Jersey

Mr. John Kraker
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Edcouch, Texas

Mr. Wayne Martin
Plains Cooperative Oil Mill
Lubbock, Texas

Dr. Harry Minor
Department of Agronomy
University of Missouri
Columbia, Missouri

Mr. Frank C. Naughton
Vice President-Technology,
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Bayonne, New Jersey

Mr. Bob Pillow
Browning Seed, Inc.
Plainview, Texas

Mr. Bill Quattlebaum
Southern Cotton Oil Mill
Lubbock, Texas

Mr. Robert Raun
Minden, Nebraska

Dr. K.C. Rhee
Food Protein Research and
Development Center
Texas A&M University
College Station, Texas

Dr. Joseph C. Roetheli
USDA-CSRS
Washington, DC

Mr. Martin Schur
Plainview, Texas

Mr. Scott Stockton
Texas Department of Agriculture
Lubbock, Texas

Mr. Robert L. Vignolo
Executive Secretary, International
Castor Oil Association
Westfield, New Jersey

Dr. John Wagner
Associate Director, Engineering
Biosciences Research Center
Texas A&M University
College Station, Texas

Dr. Keith A. Walker
Agrigenetics Company
Eastlake, Ohio

Mrs. Neoma Wall Williams
Hart, Texas

• • Appendix B • •

Summary of Federal Support for Castor, 1952-72

Castor Bean Production and Procurement Program, Crop Years 1951-54

- Program initiated at the request of the Munitions Board. (See USDA press release 304-51, dated February 5, 1951.)

- Purpose was to obtain increased quantities of castor oil for national defense use and gain further experience in domestic production of castor.

- Farmers entered into contracts with the Commodity Credit Corporation (CCC) or companies under contract with CCC.

Growing areas:

Crop	States	Estimated acreage to be planted
1951	AZ, CA, OK, TX	63,000
1952	AR, AZ, CA, OK, TX	98,000
1953	AR, AZ, CA, NM, OK, TX	125,000
1954	AR, AZ, CA, NM, OK, TX	26,000

- Price paid for dehulled seed: higher of 10 cents per pound or the market price for 1951 and 1952 crops, higher of 9 cents or market price for 1953 crop, and 6 cents for 1954 crop (adjustments were made in net weight or price for quality factors).

- Program financed by CCC, but losses paid for by funds from the Defense Production Administration.

- Discontinued in 1955 because strategic stockpile of castor oil deemed adequate.

Castor Bean Price Support Program, Crops Years 1968-71

- Program for 1968 crop established on an experimental basis to encourage domestic production of part of U.S. castor oil requirements. (See USDA press release 231-68, dated January 22, 1968.)

- Price support provided through contracts with oil mills. Mills agreed to pay producers not less than the support price for castor seed, adjusted for quality factors.

- CCC allowed to purchase oil if mills could not sell their output given the support price; limited to 30 million pounds in 1968 and 1969, 35 million in 1970, and 30 million in 1971.

- Price support set at a level to be near the average of world prices over a period of years.

Specifics:

Crop	Support level (cents per pound, dehulled)	Estimated acreage to be planted
1968	5.5	70,000
1969	4.0	30,000
1970	4.5	16,000
1971	4.5	4,500

- Discontinued because producers preferred to plant castor on acreage set aside under other support programs. (See USDA press release 440-72, dated February 8, 1972.)

Planting on Set-Aside Acreage

- During the 1960s and 1970s, farmers were periodically allowed to plant castor on acreage diverted from production under the wheat, feed grain, and cotton programs.

- Such actions were definitely permitted in 1966, 1971, and 1972 (information on other years unavailable).

- Set-aside payments were reduced for the acreage planted to castor. (See fact sheet on castor dated January 1973.)

UNITED STATES DEPARTMENT OF AGRICULTURE
Production and Marketing Administration

Washington, February 5, 1951

Castor Bean Production and Procurement Program Announced:

A program for the domestic production and procurement of 1951-crop castor beans on 90,000 to 100,000 acres, so as to assure increased supplies of this commodity in the national defense program, was authorized today by Secretary of Agriculture Charles F. Brannan at the request of the Munitions Board. Castor oil is a strategic oil which is in demand for military purposes. This program was made possible by a commitment of funds by the Defense Production Administration.

The program will be carried out by Commodity Credit Corporation and will be made available to farmers who enter into contracts either with Commodity Credit Corporation or with private companies under contract with CCC, in areas within the States of Oklahoma, Texas, California, and Arizona, for which adapted seed is available. The price to be paid these farmers for castor beans will be the higher of approximately 10 cents per pound, hulled basis, or the market price at time of delivery.

The CCC will enter into contracts with manufacturers for the purchase of farm machinery and other equipment that may be needed in connection with the production, harvesting, receiving, and hulling of castor beans; and contract for the purchase of available supplies of castor bean seed for sale to farmers in areas where the seed id best adapted in the designated states. Production will be encouraged in concentrated areas to facilitate harvesting, receiving, and hulling of beans.

The program contemplates the planting of about 27,000 acres of irrigated land in Arizona and California, 3,000 acres of irrigated land in Oklahoma, and 60,000 acres of dry land in Oklahoma and Texas. This is about the maximum acreage for which adapted seed is now available. Harvesting machinery and technical guidance also will be available to farmers participating in the program.

It is expected that the total acreage will produce approximately 78,000,000 pounds of castor beans in 1951 (for the processing of about 34,000,000 pounds of oil), plus an adequate supply of seed for planting in 1952.

The program will be financed by CCC, but losses will be reimbursed from funds provided under the Defense Production Act of 1950.

3423 (Agriculture, Washington) - - - - USDA 304-51

UNITED STATES DEPARTMENT OF AGRICULTURE

Washington, Jan. 22, 1968

USDA Announces Castor Bean Price Support Program:

The U. S. Department of Agriculture today announced that a limited price support program will be in effect for 1968 crop castor beans.

Department officials explained that the support program for castor is experimental. A price support program as not been in effect for castor and, for that reason, the final level of the price support will not be determined until after the Department can establish a parity price. A tentative support level of 5.5 cents a pound has been set, subject to a review of parity prices.

The support price will apply to the weight of dehulled castor beans, exclude foreign material and less moisture in excess of 6 percent, at locations designated in producing areas by oil mills. Price support will be made effective by CCC through contracts with oil mills. The oil mills will agree to pay producers no less than support price for castor beans. If the oil mills cannot sell products produced from the beans at prices sufficient to return the support price plus a reasonable operating margin CCC will purchase oil from the mills at prices that will provide such return. Total CCC purchases will not exceed 30 million pounds of oil.

The Department emphasized that production and processing of castor beans requires special equipment on farms and in oil mills. For this reason, it is recommended that farmers not undertake to produce the crop unless they have access to equipment needed on the farm at reasonable cost and a firm sale outlet to an oil mill which has a contract with CCC to pay not less than the support price for castor beans.

Department officials explained that the limited price support program is intended to encourage production in this country of around one-fifth of the domestic consumption of castor oil. This production should help to stabilized the supply demand-price balance over the years and provide a basis for expansion of the castor crop if needed because of emergency conditions at any time in the future.

Price support as proposed will afford producers protection against depressed market prices that result from unusually large world production in some years. The support price level is considered to be near the average of world prices over a period of years and any cost of the program to the Government should be moderate.

Castor oil is used for industrial purposes. Uses include lubricants of all types, hydraulic and recoil fluids, plasticizers and plastic artificial leather, soap, printing ink, paint lacquers, flexible coatings for electrical and other equipment, as well as certain defense uses. It is one of the stockpile items acquired and held for defense use.

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3824 USDA 231-68

Deevy (202) 388-3135
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NEWS

U. S. DEPARTMENT OF AGRICULTURE

February 8, 1972

CASTOR BEAN PROGRAM DISCONTINUED:

WASHINGTON, Feb. 8 --The U.S. Department of Agriculture today announced that no support program will be conducted for 1972-crop castor beans.

Sharply declining acreage plantings and the discontinuation of crushing by the last U.S. castor bean facility have resulted in a substantial decline in the domestic industry, USDA indicated. For 1971, there were an estimated 4,500 acres planted to castor beans, as compared to 16,000 in 1970; 30,000 in 1969 and 70,000 in 1968.

Producers indicated that use of a 1972 support program--unless the loan level were substantially increased--would not be as desirable as would the opportunity of planting the beans on acreage set aside from production of cotton, feed grain, or wheat. On Dec. 21 (Press Release USDA 4221-71), it was announced castor beans could be planted as an alternate crop on set aside acreage, with a reduction in payment related to a farm's productivity. In the 1971 program, there were 120 farms planting 3,390 acres of castor beans on set aside land.

Center of castor bean production has been in the Plainview, Texas, region.

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6166 USDA 440-72

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Stabilization and Conservation Service

ASCS Commodity Fact Sheet
1972 Castor Beans

January 1973

CASTOR BEANS

Summary of Support and Related Data

Support Level:	There has been no support program for castor beans since 1971. The support level in that year was 4½ cents per pound.
Acreage Allotments & Marketing Quotas:	None
Support Method:	While there is no support program for 1972-crop castor beans, the farmers were permitted to plant castor beans on Feed Grain, Wheat and Upland Cotton acreages which were set-aside under the respective support programs for such major commodities. At the same time, the farmer accepted a reduction in his set-aside payments for any set-aside acreages planted to castor beans.
December 1972 Situation:	A world castor oil shortage, which began to express itself price-wise in October 1971, intensified after May 1972, and is now in full bloom. New York wholesale prices for castor-oil increased from a strong 17 - 17.5 cents per pound in early 1971 to 26 cents in mid-1972 and, after September, to a peak 43.5 cents in November 1972. No appreciable price relief is expected during the calendar year 1973. Current price levels for castor-oil reflect 3 equally important factors for the U. S. industry. First, world-output has declined, particularly in Brazil, following the low prices of 1968 and 1969. No rapid return to castor plantings in Southern Brazil is foreseen even at such high price levels. A second factor has been the disappearance of U. S. government holdings of castor oil which furnished an average 20 million pounds annually to the U. S. market over a 12-year period. These supplies are now gone. Thirdly, production of castor oil from Texas-grown beans has little chance of reaching again the 40 million pound level of 1968-69. In short, no relief for castor oil supplies is expected before 1974.
CCC Investment:	The CCC sold the last of its castor oil holdings in October 1971.

Appendix C

Castor Oil Prices

Table 4. Annual Wholesale Prices for No. 1 Castor Oil, Tank Car Lots.

Year	Nominal price	Producer Price Index for oilseeds	Deflated price[1]
	Cents per pound	1982=100	Cents per pound
1965	13.24	na	na
1966	14.98	50.4	29.73
1967	19.18	46.6	41.17
1968	20.60	45.0	45.78
1969	15.18	43.2	35.13
1970	15.48	45.8	33.79
1971	17.20	51.1	33.66
1972	23.31	55.6	41.92
1973	52.57	107.8	48.76
1974	44.04	108.2	40.70
1975	31.46	92.5	34.01
1976	33.33	95.3	34.98
1977	43.42	110.3	39.36
1978	41.81	104.4	40.05
1979	44.92	114.4	39.27
1980	51.34	116.1	44.22
1981	44.38	129.3	34.32
1982	44.76	100.0	44.76
1983	59.29	114.3	51.87
1984	72.71	118.1	61.57
1985	46.71	94.4	49.48
1986	33.07	91.5	36.15
1987	39.18	99.3	39.45
1988	48.88	134.0	36.48
1989	51.70	na	na
1990	50.48	na	na

na = Not available.

[1]Calculated by dividing the nominal price by the Producer Price Index.

Sources: [11, 36].

Table 5. Monthly Wholesale Prices for No. 1 Castor Oil, Tank Car Lots.

Year	January	February	March	April	May	June	July	August	September	October	November	December
						Cents per pound						
1965	13.40	12.90	12.80	12.70	12.30	11.80	12.00	13.30	14.40	14.50	14.50	14.30
1966	14.00	14.00	14.10	14.70	15.10	15.20	15.30	15.30	15.30	15.40	15.60	15.80
1967	15.80	15.80	16.10	17.30	18.30	18.50	18.70	19.00	19.30	22.60	24.50	24.30
1968	24.50	24.00	22.20	20.90	18.20	21.50	22.00	21.10	19.50	18.70	17.70	16.90
1969	17.00	16.90	16.20	15.30	14.70	14.50	14.40	14.70	14.80	14.80	14.80	14.00
1970	14.20	14.40	14.30	13.80	14.30	14.30	15.50	15.50	15.80	18.00	17.80	17.80
1971	18.00	17.80	17.50	17.00	16.50	16.80	17.30	17.00	17.00	17.00	17.00	17.50
1972	20.10	20.50	18.50	19.50	19.80	20.80	25.50	26.00	25.00	28.00	28.00	28.00
1973	42.00	44.50	63.50	70.00	65.00	50.00	45.00	51.00	51.00	49.30	49.00	50.50
1974	48.50	48.00	47.50	47.00	47.00	47.00	45.50	45.50	38.50	38.00	38.00	38.00
1975	33.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	30.00	29.50	29.00
1976	29.00	27.50	27.50	27.50	27.50	31.50	35.00	38.50	39.00	39.00	39.00	39.00
1977	39.00	39.00	40.00	40.00	45.00	45.00	45.00	45.00	45.00	46.00	46.00	46.00
1978	46.12	46.50	46.50	47.25	46.25	40.31	39.41	37.88	37.88	37.88	37.88	37.88
1979	37.88	37.88	37.86	37.75	37.81	38.42	41.30	50.88	53.12	54.13	56.00	56.00
1980	55.70	55.70	55.75	55.56	55.03	52.00	51.00	49.65	48.00	46.45	45.25	46.00
1981	46.65	45.94	45.00	45.00	44.55	44.13	43.50	44.25	43.69	43.31	43.25	43.25
1982	42.81	43.25	43.25	43.25	44.71	45.88	46.50	45.50	45.50	45.52	45.50	45.50
1983	45.50	45.50	45.50	46.83	49.50	49.50	53.40	61.75	78.50	78.50	78.50	78.50
1984	78.50	78.50	78.50	78.50	78.50	73.75	69.00	77.30	65.00	65.00	65.00	65.00
1985	65.00	65.00	65.00	65.00	50.50	36.00	36.00	36.00	36.00	36.00	36.00	34.00
1986	34.50	34.50	34.50	34.50	33.38	32.25	32.38	32.56	31.70	31.63	32.00	33.00
1987	33.00	32.25	34.27	36.00	36.00	36.00	42.50	42.50	43.10	44.00	44.00	46.50
1988	46.50	46.50	52.50	51.38	49.88	49.50	48.75	48.00	48.00	48.00	48.50	49.00
1989	51.00	51.75	51.90	51.50	51.50	51.50	51.50	51.50	51.50	51.50	51.50	53.75
1990	54.50	53.50	52.60	52.00	51.20	51.00	51.00	51.00	45.00	43.00		

Source: [11].

• • Appendix D • •

Statistics on World Production and Trade of Castor Seed and Oil

Table 6. World Production of Castor Seed.

Country	1961-65	1966-70	1971-75	1976-80	1981-85	1986-89
	Annual average production					
	Metric tons					
India	99,360	121,160	176,360	211,460	367,420	335,500
China[1]	46,000	113,400	70,200	94,600	183,600	280,000
Brazil	267,584	356,352	424,558	272,780	259,214	165,011
Soviet Union	36,600	74,120	70,840	44,800	63,000	67,250
Paraguay[1]	15,300	9,830	20,351	21,815	25,526	45,334
Thailand	40,040	39,600	38,280	37,520	34,100	30,675
Ethiopia[1]	10,320	11,820	8,420	10,800	12,000	12,250
Romania[1]	13,728	14,953	9,980	4,540	6,740	8,875
Philippines[1]	313	241	2,660	12,000	18,600	8,725
Sudan[1]	6,356	17,049	14,556	4,470	5,000	5,950
Tanzania[1]	12,027	12,648	11,628	5,992	5,000	5,000
South Africa	13,560	4,280	4,700	5,000	5,000	5,000
Mexico	7,485	4,524	3,954	3,675	4,400	4,000
Kenya[1]	4,032	4,664	2,010	2,332	3,080	3,975
Iran[1]	9,588	9,196	6,500	4,000	3,300	3,500
Vietnam[1]	2,200	2,000	2,000	2,000	2,400	3,200
Pakistan[1]	7,840	12,642	12,057	19,092	22,333	3,168
Angola[1]	4,998	4,120	3,100	3,100	3,000	3,000
Indonesia[1]	2,000	2,888	3,068	721	1,169	1,900
Ecuador	21,400	19,427	30,401	9,955	2,461	1,659
Cambodia[1]	2,780	400	100	165	738	1,333
Uganda[1]	2,195	1,891	1,260	500	620	1,000
Yugoslavia[1]	4,358	3,166	348	3	720	633
Mozambique[1]	1,980	1,940	1,680	760	500	500
South Korea[1]	2,255	2,013	1,442	547	406	369
Peru[1]	7,701	3,816	71	9	19	20
United States	21,772	20,845	2,409	0	0	0
Argentina[1]	5,758	5,130	1,221	62	0	0
Libya[1]	3,729	457	215	0	0	0
Other[1]	6,668	3,748	3,925	5,235	8,099	6,141
World	679,928	878,320	928,293	777,405	1,036,096	1,003,967

[1]Data estimated for 1 or more years.

Source: Data from [15].

Table 7. World Trade of Castor Seed.

Exporting country	1961-65	1966-70	1971-75	1976-80	1981-85	1986-88
	Annual average exports					
	Metric tons					
China[1]	6,737	50,263	12,100	6,520	36,180	132,294
Paraguay	12,328	10,367	11,579	14,360	17,540	12,317
Philippines	258	145	2,461	10,453	19,084	6,016
Pakistan[1]	607	1,190	3,553	11,728	9,605	3,018
Sudan[1]	4,221	9,903	8,056	3,571	1,216	1,876
Kenya[1]	4,973	3,901	1,400	2,085	1,202	1,825
Tanzania	15,072	9,846	9,465	2,768	793	736
Indonesia[1]	609	2,176	2,856	856	520	382
Sri Lanka[1]	0	0	0	526	2,242	365
Ethiopia	6,312	2,174	2,032	752	407	283
Ecuador	20,677	10,489	18,046	2,131	221	0
Thailand	38,205	34,017	30,797	34,869	106	0
Angola[1]	802	3,026	1,681	760	20	0
Libya[1]	3,617	438	91	0	0	0
Other[1]	16,938	6,605	3,933	1,895	3,187	3,283
World	130,835	144,136	108,051	93,262	92,229	162,396

Importing country	1961-65	1966-70	1971-75	1976-80	1981-85	1986-88
	Annual average imports					
Brazil	0	0	9,024	9,091	14,652	56,798
West Germany	27,607	32,481	29,872	29,396	30,394	37,599
Japan	35,886	55,802	45,724	37,101	33,629	35,485
Italy	9,573	11,055	5,119	7,452	8,328	10,533
Thailand	0	0	0	7	1	8,913
Taiwan	0	0	104	674	683	2,612
South Korea	0	379	487	359	474	2,397
Argentina	0	703	1,838	1,258	1,147	715
Belgium-Luxembourg	3,679	1,138	4	209	18	71
France	21,542	20,476	13,579	4,958	18	49
United States	2,764	176	5	2	1	11
United Kingdom	18,676	21,231	12,227	4,778	2,604	0
Netherlands	2,388	43	0	0	100	0
Czechoslovakia	2,178	0	0	0	0	0
Other[1]	5,456	4,178	1,877	820	2,304	3,170
World	129,750	147,663	119,861	95,966	94,355	158,354

[1]Data estimated for 1 or more years.

Source: Data from [19].

Table 8. World Production of Castor Oil.

Country	Annual average production					
	1961-65	1966-70	1971-75	1976-80	1981-85	1986-89
	Metric tons					
Brazil	115,962	136,964	159,087	138,600	99,540	100,350
India[1]	35,880	37,720	60,800	69,600	120,800	85,750
China[1]	15,967	24,996	23,800	36,652	61,209	65,341
Soviet Union[1]	12,000	26,980	25,260	18,700	21,740	26,525
West Germany[1]	12,760	15,040	14,160	13,220	13,500	17,000
Japan[1]	16,200	25,600	20,400	17,000	15,071	15,416
Thailand[1]	324	510	622	2,178	14,134	15,313
Ethiopia[1]	1,568	4,094	2,765	4,395	5,082	5,241
Italy[1]	4,410	5,224	2,356	3,434	3,834	5,089
Romania[1]	5,976	6,524	4,318	1,934	2,870	3,810
South Africa[1]	4,808	2,038	1,983	2,020	1,856	2,025
Iran[1]	4,083	3,937	2,824	1,857	1,702	1,797
Tanzania[1]	10	185	665	649	1,223	1,609
Mexico[1]	1,001	1,203	1,240	1,344	1,680	1,600
Philippines[1]	22	38	56	67	54	1,593
Vietnam[1]	777	855	855	855	978	1,314
South Korea[1]	953	1,030	826	389	378	1,300
Sudan[1]	574	2,319	1,416	1,240	1,407	1,287
Angola[1]	1,626	422	514	929	1,219	1,228
Ecuador[1]	0	0	1	3,297	3,357	1,043
Pakistan[1]	2,725	3,689	3,164	3,178	3,867	1,030
Kenya[1]	36	139	191	87	410	971
United Kingdom[1]	8,580	9,760	6,080	1,800	1,137	600
Yugoslavia[1]	1,947	1,392	154	2	320	284
Belgium-Luxembourg[1]	1,636	476	3	50	8	42
Peru[1]	3,006	1,642	31	4	8	10
Netherlands[1]	1,032	18	0	0	29	7
United States[1]	10,734	9,253	2,195	0	0	0
France[1]	8,460	8,360	6,400	2,321	3	0
Other[1]	3,701	2,756	2,740	1,435	2,563	2,263
World	276,762	333,165	344,907	327,239	379,978	359,839

[1]Data estimated for 1 or more years.

Source: Data from [15].

Table 9. World Trade of Castor Oil.

Exporting country	1961-65	1966-70	1971-75	1976-80	1981-85	1986-88
	Annual average exports					
	Metric tons					
Brazil	96,028	124,760	129,845	129,186	71,877	79,852
India[1]	25,060	14,330	29,009	40,208	67,500	39,667
China[1]	110	6,226	704	3,780	10,040	26,495
Thailand	33	16	6	1,429	9,791	8,950
West Germany	2,653	2,353	3,310	3,560	3,735	5,430
Netherlands	288	963	1,360	1,688	1,135	2,359
Italy	25	21	34	256	752	1,716
Ecuador	0	0	0	3,267	3,064	1,056
United Kingdom	994	958	566	503	300	379
France	1,023	1,935	1,402	765	343	340
Japan	2,455	5,238	2,244	811	395	181
Belgium-Luxembourg	967	15	154	93	131	112
Yugoslavia	818	238	0	0	9	81
Romania[1]	4,460	3,079	140	0	0	0
Other[1]	1,160	916	1,141	1,299	1,640	941
World	136,073	161,047	169,916	186,831	170,712	167,558

Importing country	1961-65	1966-70	1971-75	1976-80	1981-85	1986-88
	Annual average imports					
France	24,885	36,016	36,245	38,218	41,535	41,781
United States	50,103	52,008	42,672	49,738	35,216	36,850
Soviet Union	14,920	8,440	16,341	33,110	37,520	35,700
West Germany	3,861	7,691	8,781	13,175	11,544	10,988
United Kingdom	16,505	17,407	17,450	15,622	7,491	8,420
Poland	2,000	3,362	5,002	4,907	3,620	4,695
Netherlands	1,733	5,186	3,859	3,092	2,434	3,776
Italy	127	1,246	3,086	2,428	2,286	2,810
Japan	2	474	2,890	3,849	4,730	2,619
Spain	1,609	2,171	2,240	2,664	2,052	2,479
Czechoslovakia[1]	3,680	4,958	3,000	1,060	1,220	1,133
Canada	2,455	2,548	2,268	1,442	1,224	944
Belgium-Luxembourg	1,486	2,481	3,022	1,692	1,177	714
East Germany[1]	756	1,896	2,900	1,660	100	0
Other[1]	10,052	14,336	15,325	15,020	17,614	15,061
World	134,174	160,221	165,081	187,678	169,762	167,972

[1]Data estimated for 1 or more years.

Source: Data from [19].

• • Appendix E • •

Department of Defense Strategic and Critical Materials Program

The Strategic and Critical Materials Stock Piling Act mandates that a stock of strategic and critical materials be maintained to decrease dependence upon foreign sources of supply in times of national emergency. The Act requires that the stockpile be sufficient to cover U.S. needs for at least 3 years of an emergency.

In addition to maintaining stocks of materials, the Act also requires actions to encourage the conservation and development of domestic sources of strategic and critical materials [37].

Ricinoleic/sebacic acid products are the specific castor oil derivatives included in the program. As of September 30, 1988, DOD listed 8.8 million pounds as the target amount for the stockpile. However, current inventory is slightly over 5 million pounds, with a value of $9.7 million. This leaves a deficit of about 3.7 million pounds [34].